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**IMPACT DAMAGE IN FILAMENT  
WOUND COMPOSITE BOTTLES**

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Increasingly, composite materials are being used in advanced structural applications because of the significant weight savings they offer when compared to more traditional engineering materials. The higher cost of composites must be offset by the increased performance that results from reduced structural weight if these new materials are to be used effectively. At present, there is considerable interest in fabricating solid rocket motor cases out of composite materials, and capitalizing on the reduced structural weight to increase rocket performance. However, one of the difficulties that arises when composite materials are used is that composites can develop significant amounts of internal damage during low velocity impacts. Such low velocity impacts may be encountered in routine handling of a structural component like a rocket motor case. The ability to assess the reduction in structural integrity of composite motor cases that experience accidental impacts is essential if composite rocket motor cases are to be certified for manned flight. While experimental studies of the post-impact performance of filament wound composite motor cases have been performed (2,3), scaling impact data from small specimens to full scale structures has proven difficult. If such a scaling methodology is to be achieved, an increased understanding of the damage processes which influence residual strength is required.

The study described herein was part of an ongoing investigation of damage development and reduction of tensile strength in filament wound composites subjected to low velocity impacts. The present study, which focused on documenting the damage that develops in filament wound composites as a result of such impacts, included two distinct tasks. The first task was to experimentally assess impact damage in small, filament wound pressure bottles using x-ray radiography. The second task was to study the feasibility of using digital image processing techniques to assist in determining the 3-D distribution of damage from stereo x-ray pairs.

For the first task, the experimental determination of impact damage in filament wound bottles, 5.75 in. diameter bottles were used. The bottles were wound with a pattern XOOXOO, where X represents a layer of helical windings (in this case, a layer with strands oriented at  $\pm 11.5^\circ$  to the cylinder axis) and O represents a single layer with strands oriented in the hoop direction. Note that a helical layer has twice the thickness of a hoop layer, since a helical layer represents strands oriented in two directions. Three different material systems were studied, all of which were reinforced with IM7 carbon fibers. The three different matrix systems were a standard epoxy (3501-6ATL) and two toughened epoxies (X8553-45, 977-2).

A drop tower-type impact testing machine was used to impact the specimens, which were placed in a removable cradle which was attached to the bottom of the test frame for impact testing. Impact energy was controlled by adjusting the height from which the crosshead assembly was dropped. Based on some preliminary impact tests, three impact energies -- low (3.0 in.-lb.), intermediate (5.0 in.-lb.) and high (7.0 in.-lb.) were used. Each bottle used in the damage documentation study was subjected to three impacts (one at each of the three levels) at locations evenly spaced around the circumference of the bottle. Dynamic impact data was collected from the 0.5 in. diameter instrumented impact tup during impact.

After being impacted, the domes were cut off of the bottle and the cylindrical region was cut into 3 segments, with each segment containing a single impact site. Each segment was then inspected via dye-penetrant enhanced x-ray radiography (1). The dye penetrant used was a zinc iodide solution (60 g zinc iodide, 10 ml. water, 10 ml. isopropyl alcohol, 10 ml. Kodak "Photo-Flo 200"). A small dam encircling the impact site was made using plumbers putty. This dam was filled with the zinc iodide solution, which was allowed to seep into the specimen for at least four hours. The dye penetrant filled those damage events (matrix cracks, delaminations) which it could flow into. The zinc iodide thus rendered these areas more opaque to x-rays than the surrounding undamaged regions. Three radiographs were taken of each segment using different angles of incidence of the x-ray beam -- one with an angle of incidence of  $82.5^\circ$ , one with an angle of incidence of  $90^\circ$ , and one with an angle of incidence of  $97.5^\circ$ . The same cradle used for the impact tests was used to hold the x-ray film and segment during radiography, so that the x-ray film was wrapped around the curved segment. The  $90^\circ$ , or normal incidence x-ray provided a planform view of damage in the specimen. The other two x-rays formed a stereo pair and, when viewed using a stereo viewer, provided a three dimensional view of damage in the specimen (1). Using such a stereo imaging process, it was possible to resolve the location of damage through the thickness of the specimen.

A normal incidence x-ray radiograph taken from a specimen with the standard epoxy matrix subjected to a high energy impact is shown in Fig. 1. Note that the horizontal direction in the radiograph corresponds to the hoop direction. Also, in an undamaged specimen, the radiograph should have a darker tone at the left and right edges because of the curvature of the cylindrical segment. The sharp lines that appear in the radiograph correspond to matrix ply cracks that were decorated with dye penetrant. Such features are evident in all three of



Figure 1. X-ray radiograph of Specimen C 067-068, high energy impact.

the filament winding directions. The oval region that is centered on the actual impact site corresponds to the delaminated area of the specimen. A stereoscopic inspection of the damage reveals that delaminations occur at every interface, and that the overall oval geometry results from the "superposition" of the distinct delaminations.

The delamination seen in Fig. 1 is quite extensive, covering almost the full height of the cylindrical portion of the pressure bottle. This is typical of the specimens with the standard epoxy matrix. Similar damage states are seen in the specimens with toughened epoxy matrices, but the size of the damaged region is smaller in the toughened systems than in the standard epoxy system. In addition, lower impact energies generally (but not always) yield smaller delaminated areas.

Figure 1 also shows two heavily damaged (very dark) areas located away from the central impact site. A close stereoscopic inspection of these regions located to the left and right of the impact site reveals that there is fiber fracture at these locations. The fiber fracture developed in the helical layers, especially in the innermost helical layers. The location of this fiber fracture was apparently governed by the deflected shape assumed by the pressure bottle during impact. While this type of fiber fracture was most common, a second type of fiber fracture, as represented by the radiograph in Fig. 2, was also observed. This second fiber fracture mode has fiber fracture in the exterior hoop layers emanating from the impact site. The delaminated area is relatively small, even for a toughened epoxy, and closely follows the line of fiber fracture. At present, the factors influencing which fiber fracture mode will dominate are not well understood. It is believed that preexisting flaws can promote hoop direction fiber fracture.

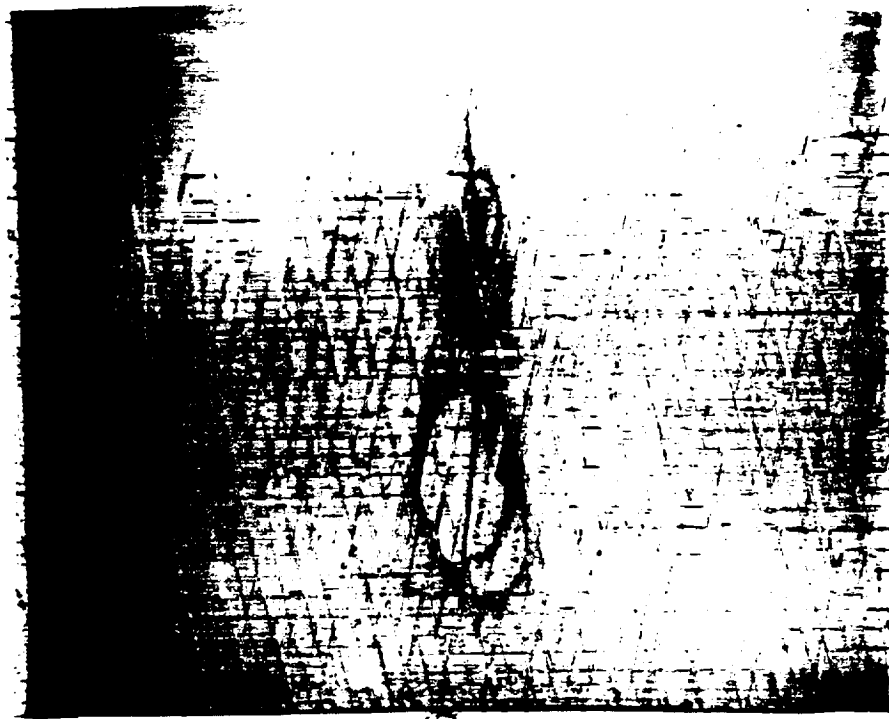


Figure 2. X-ray radiograph of Specimen C 113-114, medium energy impact.

The second task undertaken in the present study was to assess the feasibility of determining the 3-D distribution of damage using digital image processing of stereo radiographs. In this preliminary effort, attention was focused on extracting damage information from a single radiographic image, and representing that information in digital form. Reconstruction of the 3-D damage state would ultimately be accomplished by reconciling such digital information from two or more views of the composite.

To this point, efforts have focused on extracting ply crack information from radiographs. First, the radiograph is digitized using a scanner, and stored using the Tagged Image File Format, i.e., a the digital image is stored as a TIFF file. An 8 bit digitization was used, resulting in a 256 shade gray scale. A variety of image processing routines were written in the Turbo C++ programming language, for "enhancing" such digital images and for extracting features from the image. In this preliminary study, the best results were obtained by first sharpening the digitized image using an unsharp filter [4]. Then, a constant gray value (about 85% of the image average was found useful) was subtracted from the image. This eliminated extraneous features in the largely uniform gray area surrounding the damaged zone. Finally, a line detection routine was developed for extracting lines of a prescribed orientation from the image. Using this line extraction routine, it was possible to isolate hoop direction, or  $+\theta$  direction, or  $-\theta$  direction ply cracks. The extracted lines correlated quite well with features in the original image.

In summary, the experimental program has shown that toughened epoxy systems do reduce the amount of matrix damage, especially delamination, that develops during impact. Fiber fracture has been found to follow one of two modes -- one mode has fiber fracture in the interior helical layer at locations dictated by the deflected shape of the pressure bottles, and one mode has fiber fracture in the exterior hoop layers emanating from the impact site. In addition, a preliminary study has indicated that digital image processing techniques show promise for extracting the 3-D damage distribution from stereo radiographs.

#### REFERENCES

1. Jamison, R.D., "Advanced Fatigue Damage Development in Graphite Epoxy Laminates," Ph.D. dissertation, Virginia Polytechnic Institute and State University, Aug. 1982.
2. Madsen, C.B., Morgan, M.E., and Nusimer, R.J., "Scaling Impact Response and Damage in Composites. Damage Assessment for Composites - Phase I Final Report," AL-TR-90-037, Hercules Aerospace Co. for Astronautics Laboratory, AFSC, Edwards AFB, CA, August 1990.
3. Morgan, M.E., Madsen, C.B., and Watson, J.O., "Damage Screening Methodology for Design of Composite Rocket Motor Cases," JANNAF Propulsion Meeting, Indianapolis, Feb. 1992.
4. Pratt, William K. Digital Image Processing, 2nd Ed., John Wiley and Sons, New York, 1991.